Technical Report Documentation Page

1. Report Title

Role of microbial induced calcium carbonate precipitation on corrosion prevention

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5. Abstract

Internal stresses (due to mechanical loads, temperature changes, etc.) can induce microscopic cracks in portland cement concrete, which may continue to grow upon the application of additional stresses. These cracks can provide pathways for harmful chemicals to ingress. Research in the field of concrete materials has shown that it is possible to develop a smart cement-based material that is capable of self-healing by leveraging the metabolic activity of microorganisms to induce biogenic calcium carbonate precipitation. This project investigates the application of a using this biomimetic approach to improve the corrosion resistance of concrete.

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Role of microbial induced calcium carbonate precipitation on corrosion prevention

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Goals and Objectives

The overarching goal of this project was to advance the understanding on how microbial-induced calcium carbonate precipitation can be leveraged to improve the durability of concrete. The specific objective of this project was to determine the efficacy of biogenic calcium carbonate precipitation to improve the corrosion resistance of concrete of cracked concrete.

Background

Corrosion of reinforcement is one of the leading causes of deterioration in reinforced concrete, Once corrosion initiates it further opens up a pathway to reinforcement for water and other chemical ingress, which makes concrete more prone to strength and durability loss. Thus, efforts to improve the quality of concrete through reducing its permeability and/or increasing its resistivity helps not only to prevent corrosion, but also aids in reducing the rate of corrosion once corrosion has been initiated.

Microbial induced calcium carbonate precipitation has been proven to be an effective approach to sealing cracks in concrete, however limited work has been conducted with respect to the corrosion resistance of cracks that have been healed via microbial induced calcium carbonate precipitation. The microbes used in microbial induced calcium carbonate precipitation typically needs a food source to survive and when used in concrete, calcite is the dominant calcium carbonate polymorph that is precipitated from these microbes (Williams et al., 2017). Jonkers et al. (2009, 2010) added expanded clay particles containing bacterial spores and calcium lactate into concrete. The calcium lactate served as food source for the bacteria. Other researchers have also incorporated bacteria such as, *Bacillus pasteurii, Bacillus cohnii*, and *Bacillus subtilis*, to biogenically induce calcite precipitation in cement-based materials (Ramachandran et al., 2001, Whiffin et al., 2007, Bundur et al., 2014, Nosouhian et al., 2015). Achal et al. (2013) looked into crack remediation using bacterial cells on pre-cracked unreinforced concrete specimens. Crack remediation was also carried out via ponding and injection of bacterial solutions by Kumar et al., (2013) and Chaurasia et al. (2014).

In this research, we tested the effectiveness of using a biomimetic approach using microbial induced calcium carbonate precipitation to improve corrosion resistance of reinforced specimens that have been pre-cracked prior to corrosion testing.

Experimental Program

Experimental Matrix

Reinforced mortar specimens (5" x 5" x 3.5") were cast using three different aqueous solutions: water, nutrient solution, and bacterial solution. Specimens cast using water served as control specimens. The nutrient solution was prepared as per ATCC instruction for culture of *B. cohnii*. The bacterial solution was a mixture of cultured bacteria along with the nutrient solution. The bacteria, *B. cohnii*, was procured from ATCC, USA. *B. cohnii* was added to the nutrient solution at OD_{600}=0.6 and then this bacterial solution was immediately used for preparing the mortar. No encapsulation was conducted to the bacteria prior to mixing the bacterial solution with the cement and sand. Rather, the bacteria was incorporated into the mortar in a vegetative state. Specimens with nutrient and bacterial solutions also contained 1% calcium lactate (with respect to mass of cement) at the time of mixing. All mortar specimens were cast with an ASTM C150 Type I/II cement at solution-to-cement (s/c) mass ratio of 0.5 and cement-to-sand volume ratio of 1:3.
To create the specimens, wooden formwork was assembled and one six-inch long #4 rebar was placed at the center of the specimen. Once mixed, the mortar was poured into wooden molds.

To create a crack at the center of the specimens (see Figure 1), stainless steel shims (width 0.25mm and depth 10 mm) were inserted into the surface of the specimens and removed after initial set. Studies (VDOT 2018, Marsavina et al., 2009) have shown that removable shims can be an effective approach to studying the effects of chloride ingress in cracked cement-based materials. The shim size was selected to be slightly greater than the widest crack that is likely to be healed from autogenous healing. As per BS 2007 (1987) cracks up to 0.2 mm wide will autogenously seal within 28 days; cracks up to 0.1 mm will seal within 14 days. Specimens were demolded after 24hrs and cured for 28 days in a fog room. After 7 days of curing 1% calcium lactate solution was sprayed at the crack face.

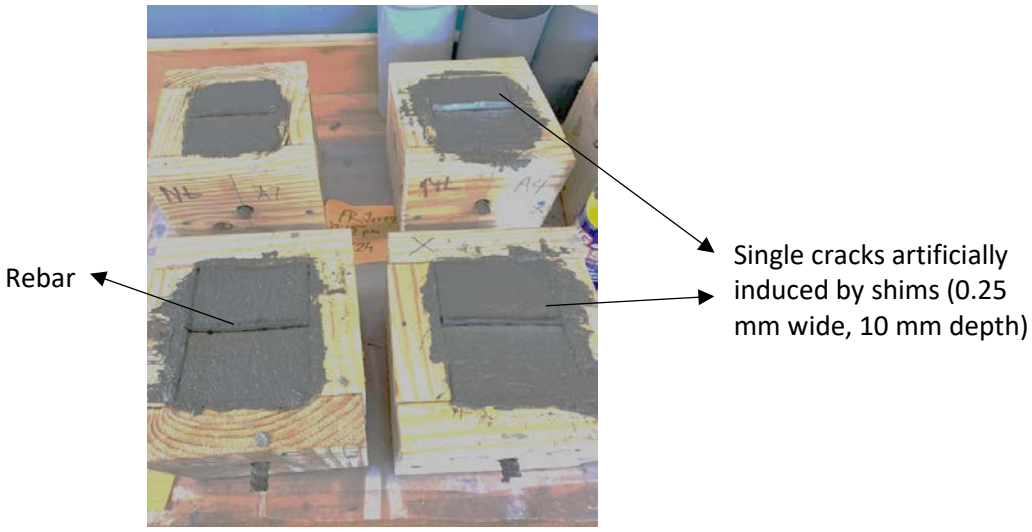

Figure 1: Shim-simulated cracks on specimens

Corrosion setup

After curing, the specimens were removed from the fog room and submerged in 3.5% NaCl solution for 24hrs. NaCl submergence was carried out to ensure sufficient saturation to facilitate electrical current flow for when the specimens were placed in the corrosion setup (Figure 2). The corrosion process was induced by maintaining a constant anodic potential of 40V across the specimens. A constant positive potential was applied to the rebar in the specimen and the current from the reinforcing steel bar to counter the electrode was measured periodically. Cotton gauze was rolled around the specimen to evenly spread the NaCl solution, after which a stainless steel mesh was placed around the gauze wrapped specimen. The exposed bar was then connected to the positive terminal (making the bar as an anode) of a DC power source while the negative terminal was connected to the steel mesh. A constant drip of NaCl solution to the mortar specimen was used to promote chloride ion ingress to the specimens. A similar corrosion setup used by Achal et al. (2013) however, the specimens used in that work were crack-free.

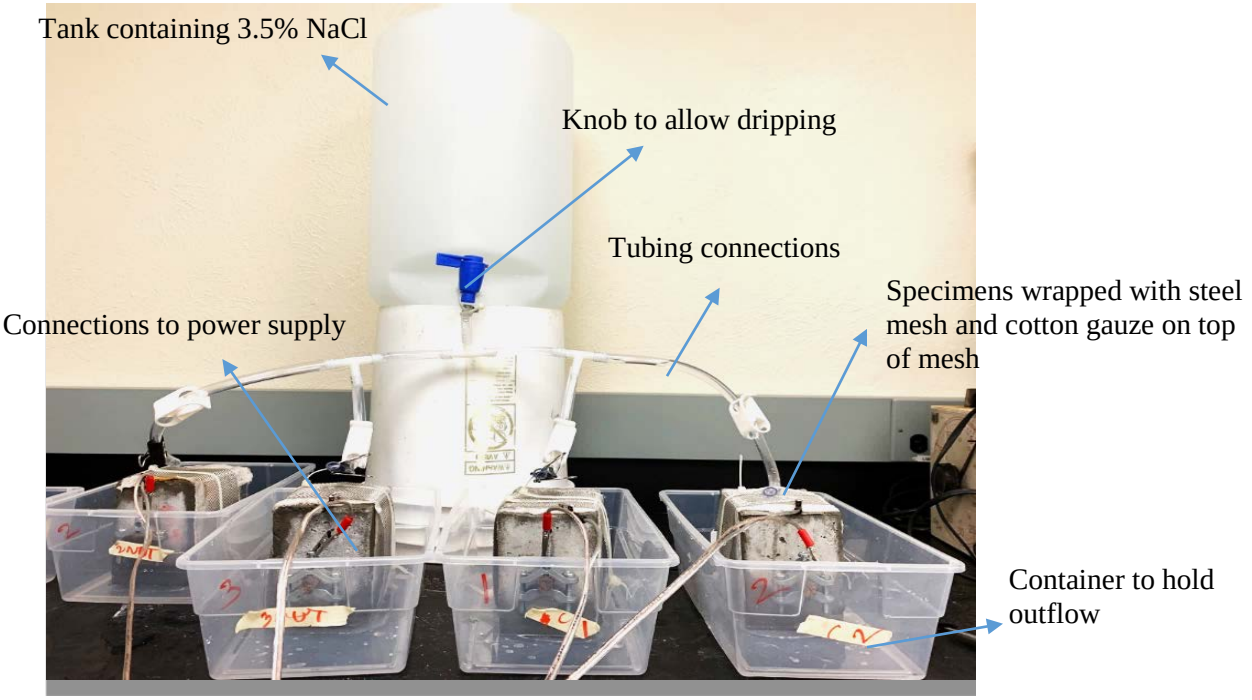

Figure 2: Corrosion setup

Key Findings

Figure 3 presents the results of the measured current versus time plot for the neat, nutrient and bacterial reinforced mortars. 3 samples were cast for each mortar type and the figure presents the averaged data. A constant potential was applied for 7 days on all of the specimens and the corresponding current was recorded. Initially, the plan was to apply the potential for 24 hours each day. However due to technical issues after Day 4 the power supply was not able to be run constantly. Thus for Days 4 through 8, the current was applied for 8 hours each day versus 24

hours. From Day 1 to Day 4, a steady increase in current was measured in the control specimen. At the end of the testing period, it can be seen that the bacterial specimen displayed significantly lower current values than the neat specimen (i.e., control specimen). Additionally, the current measured in the bacterial specimen was lower than nutrient specimens at all times. This shows that there is a difference between the nutrient and bacterial solutions and that the behavior seen in the bacterial solution cannot be solely attributed to due to abiogenic carbonate formation due to the nutrient media (Williams et al., 2017). Rather, the bacterial concrete specimens, due to microbial calcium carbonate precipitation, is able to significantly improve the corrosion resistance of cracked concrete.

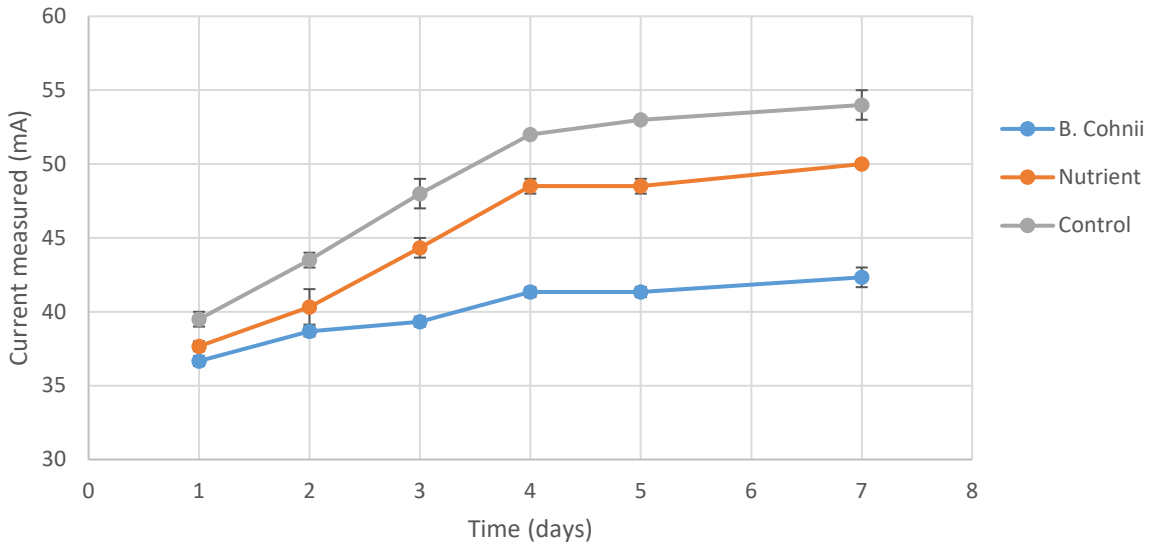

Figure 3: Current-time relationship for control, nutrient and B. Cohnii specimens

Conclusions

Use of biogenic calcium carbonate precipitation to improve the corrosion resistance of cracked concrete was investigated. The results show that inoculation of vegetative bacterial cells is an effective approach to improve corrosion resistance of cracked reinforced specimens. Future work would consist of replicating this corrosion test with different crack parameters (depth, width, number of cracks, etc). Moreover, calcium source dosage is also expected to impact calcite deposition; hence testing with different dosages of calcium lactate could also be carried out in future.

Acknowledgements

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Dissemination Products

The results of the work was presented at the ACI Fall 2019 convention in Cincinnati, Ohio. The presentation was titled “Role of Microbially Induced Calcium Carbonate Precipitation (MICCP) on Corrosion Prevention” and was presented on October 21, 2019 in the *Recent Developments in Bio-Inspired Cementitious Materials* session. ACI Committees 130-TG1, 201 and 236 sponsored this session. In addition, two manuscripts based on the results of this work are being prepared for consideration for publication in ACI Materials Journal and Concrete International. The manuscript for the Concrete International will be submitted through ACI Committee 236.